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The origin of annual lamination in stalagmites from Katerloch Cave (Austria)

R. Boch (1), C. Spötl (1) and S. Frisia (2)

(1) Institut fuer Geologie und Palaeontologie, Leopold-Franzens-Universitaet Innsbruck, Innsbruck, Austria (ronny.boch@uibk.ac.at)

(2) School of Environmental and Life Sciences, University of Newcastle, Australia

Katerloch Cave is located at the southeastern fringe of the Alps and opens at an altitude of 900 m a.s.l. The cave is well known for its rich speleothem decoration and high growth rates (0.2-1 mm/yr) of the prevalent candle-stick stalagmites are corroborated by petrography as well as U-Th dating. A monitoring program is underway since 2005 in order to understand speleothem growth dynamics and to provide a calibration for paleoclimate interpretations of stalagmite records. The latter consist of low-Mg calcite and show a macroscopic lamination of alternating white, porous laminae and translucent, dense laminae. The laminae reflect the changing crystal fabric, i.e. the abundance and distribution of air- and water-filled pores. Stable C and O isotope analyses (0.1 mm resolution) along the central stalagmite growth axes reveal a pronounced millimetre-scale variability of the δ^{13}C values while the δ^{18}O values show more gradual changes across laminae. Importantly, high δ^{13}C values typically coincide with translucent, dense laminae and low values correspond to the white, porous laminae. Trace elemental compositions also reveal short-term changes, whereas high Mg and low Sr and Ba concentrations typically correlate with high C isotope values and thus also with the lamination.

Air temperature in Katerloch Cave follows the seasonal cycle of the free atmosphere, although the temperature amplitude is progressively attenuated toward the deeper parts of the cave. Cave air CO_2 concentration and C isotope values vary seasonally with high pCO_2 and low δ^{13}C values during the warm season and vice versa during the cold season. Drip water pH, δ^{13}C values and calcite saturation state also reveal a seasonal cycle suggesting a close relationship between cave air and drip water. Drip water δ^{18}O and δD values, however, lack a seasonal variability, thus indicating seepage water supply from a well-mixed aquifer with a mean residence time exceeding one year. This pattern of (seasonally) variable δ^{13}C and rather invariant δ^{18}O values was also confirmed by studying modern calcite precipitates on glass slides.

The observed patterns suggest a dominant control exerted by the seasonally changing cave ventilation. A high gradient between the outside temperature and the cave interior temperature during winter results in a marked air density contrast drives ventilation. This air flow changes the chemical and isotopic composition of cave air and imparts on the drip water chemical and C isotopic composition by modulating the degree of CO_2 degassing and concomitant calcite precipitation. Thus, the seasonality contrast is the single most important factor controlling speleothem growth dynamics in Katerloch Cave. Dense, translucent laminae form during the cold season when an enhanced air flow results in low cave air pCO_2, high cave air and drip water δ^{13}C values, high Mg contents and high calcite supersaturation. The white, porous laminae form during the warm season under opposite conditions. Our results are in good agreement with a similar monitoring study conducted in the St. Michaels Cave of Gibraltar (Mattey et al., EPSL 2008). The Gibraltar stalagmites show a similar lamination pattern and cave ventilation is also identified as the dominant control on drip water composition and petrography inasmuch as light, porous calcite laminae form during times of high pCO_2values. In contrast to Katerloch Cave, however, these high values occur during the cold season underscoring the importance of the local cave setting on speleothem proxy data.